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Exploring the drivers of green supply chain management in the Chinese electronics industry: Evidence from a GDEMATEL–AISM approach

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ABSTRACT

The electronics industry plays a crucial role in our information-based and intelligent society, but it also contributes significantly to environmental pollution. This study aims to explore the factors that drive green supply chain management (GSCM) in this industry using a mixed-method approach. Initially, we conduct a comprehensive literature review and interview three experts to identify ten key variables influencing GSCM. Subsequently, we propose a novel method called Gray Decision-Making Trial and Evaluation Laboratory–Adversarial Interpretive Structure Modeling (GDEMATEL–AISM) to analyze the interactions, relationships, and hierarchical structure of these driving factors, visually representing them. To ensure the robustness of our findings, we perform sensitivity analysis by considering different scenarios with expert weights. For model evaluation, we utilize a case study within China's electronics industry. Our research reveals that green innovation exerts the most significant influence on GSCM practices. Additionally, green marketing, green manufacturing, and production needs emerge as crucial short-term priorities. To promote the sustainable development of GSCM, we propose corresponding strategic measures that focus on these key drivers. These insights provide valuable guidance for practitioners and decision-makers seeking to foster sustainable practices within the electronics industry.

1. Introduction

1.1. General overview

The electronics industry has experienced remarkable growth over the past two decades, playing a pivotal role in global industrialization and driving economic development. For instance, in 2021, the industry's revenue in China reached CNY 2,3627.93 billion, exhibiting a substantial growth rate of 16.6% (China Federation of Electronics and Information Industry, 2022). However, this rapid expansion and the consumption of non-renewable resources have also resulted in adverse environmental consequences. Improper disposal of electronic waste, along with significant pollution such as air and water pollution, chemical emissions, and global warming, have been observed (Awasthi and Li, 2017; Geng et al., 2017).

1.2. Literature review

The electronics industry operates within a complex and global supply chain (Aelker et al., 2013), facing challenges such as regulatory difficulties and poor environmental performance. Recognizing that the traditional supply chain management model falls short in addressing green and sustainable development requirements, researchers and practitioners have put forth the concept of Green Supply Chain Management (GSCM) as a potential solution to enhance the environmental performance of the electronics industry. Acknowledging the adverse impact of the electronics sector on society, the signing of international agreements such as the Kyoto Protocol, Paris Agreement, and Environmental Technology Action Plan has endorsed and encouraged the adoption of GSCM (Sundarakani et al., 2010). GSCM can be defined as the integration of environmental concerns into sustainable supply chain management practices among organizations (Sarkis et al., 2011). Applying GSCM principles to optimize and enhance supply chain

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management is vital for promoting green development in various areas, including procurement, marketing, and logistics. This approach incentivizes decision–makers and stakeholders while contributing to greater sustainability (Schmidt et al., 2017; Li et al., 2016; Younis et al., 2016). Recent studies have confirmed the significance of GSCM in driving a company's green development. For instance, Chatterjee et al. (2018) utilized the R'AMATEL–MAIRCA method to evaluate the GSCM supplier selection of a Taiwanese electronics company. Huang et al. (2021) examined Taiwanese manufacturers of electrical and electronic products and found that GSCM practices have a significant positive impact on organizational performance. Investigating green market orientation, Borazon et al. (2021), employed a structural equation modeling approach and discovered a positive correlation between GSCM capability and environmental and economic performance in the electronics industry. Khan et al. (2021) focused on small and medium-sized enterprises in the Pakistani manufacturing industry, employing a structural model to demonstrate that GSCM mediates the relationship between intellectual capital and financial and environmental performance to some extent. Ilyas et al. (2020) explored small and medium-sized enterprises in Pakistan's emerging markets, investigating the role of top-level management and government support in GSCM and reinforcing the importance of GSCM for such enterprises. Zhao et al. (2018) applied a system dynamics model to actual operations in the electronics industry and demonstrated that GSCM can mitigate the bullwhip effect, improve supply chain coordination, and minimize waste.

In GSCM practices, decision-makers face the challenge of establishing evaluation standards to assess the accuracy of their decisions. However, this task becomes difficult due to the existence of multiple conflicting standards within GSCM practices. Moreover, decision-makers encounter difficulties in selecting the most suitable management means or methods that align with all of these standards. As a result, the GSCM process is predominantly regarded as a multi-criteria decision-making (MCDM) problem. To address this, researchers have integrated and expanded various MCDM methods, each tailored to specific backgrounds and objectives. These refined methods have demonstrated notable practical applications across different fields (Mardani et al., 2015).

The Decision-Making Trial and Evaluation Laboratory (DEMATEL) method offers a means to identify interdependent relationships among various influencing factors from the perspective of decision-makers. It has found widespread application in real-world decision analyses, including smart city construction (Braga et al., 2021), corporate social performance (Zhao et al., 2021), and risk assessment (Yazdi et al., 2020). A DEMATEL-based method was proposed by Kaur et al. (2018) to address obstacles in GSCM practices by examining causal and outstanding relationships. Li and Mathiyazhagan (2018) utilized the DEMATEL method to develop a set of sustainable measurement indicators for small enterprises involved in automobile component production. Lin et al. (2018) employed AFDEMATEL technology to explore uncertain influencing factors and establish reasonable fuzzy causal relationships, leveraging approximate fuzzy arithmetic for various GSCM practices factors. Osintsev et al. (2021) developed a combined DEMATEL–ANP method-based logistics flow index ranking approach, allowing for the adjustment of actual parameters in GSCM logistics flows.

The Adversarial Interpretive Structure Modeling (AISM) method, derived from the Interpretive Structure Modeling (ISM) method, offers a novel technology that inherits its advantages. It facilitates the identification of hierarchical structural relationships among elements within a system and presents them through topological graphs. While no existing research specifically applies AISM to GSCM, it has been successfully employed in various decision-making problems and influencing factor analyses, such as engineering parameter selection (Sun et al., 2022), airline transportation evaluation (Li et al., 2022), and port performance evaluation (Liu et al., 2022).

In recent years, the combination of DEMATEL technology and gray theory has gained widespread usage in addressing performance evaluation problems. This integration of gray theory with the DEMATEL method acknowledges the inherent imprecision of information in human judgment and decision-making processes (Su et al., 2016). By uncovering key factors that may contribute to green business failure, (Cui et al., 2019) concluded that the Gray Decision-Making Trial and Evaluation Laboratory (GDEMATEL) method enhances the accuracy of decision evaluation. Kumar and Anbanandam (2020) offered valuable management and theoretical insights for policymakers and researchers in the freight industry. Zheng et al. (2022) applied the GDEMATEL method to investigate flood risk in urban areas, particularly mega-cities, and found it to be effective in identifying critical risk areas. Jafari-Sadeghi et al. (2022) utilized the GDEMATEL method in a study focusing on high-tech SMEs, exploring and evaluating drivers that promote their agility. The combination of gray theory and the DEMATEL method is fitting since the experts' opinions on key factors pertaining to green supply chain practices in the electronics industry are not well-defined.

GSCM encompasses various driving factors, including green marketing (Chan et al., 2012), internal green management (Vijayvargy et al., 2017), and green logistics (Luthra et al., 2016). While several studies have acknowledged the contribution of these factors to GSCM development, their interplay and impact on driving GSCM practices within the electronics industry remain unclear. Thus, this study aims to investigate the driving factors of GSCM in the electronics industry and unveil their interdependence. To accomplish this, we employ the DEMATEL method, which effectively explores the causal relationships and significance of different factors (Liu et al., 2021). Furthermore, we utilize the AISM method, an extension of the ISM method, to break down the complex system components into more manageable parts (Li et al., 2022). By combining the DEMATEL and AISM methods, we not only identify the relationships between different driving factors but also understand their impacts. Through topological operations, we visualize the topological structure of this system, enabling us to elucidate the intricate relationships in GSCM practices. Additionally, we enhance the DEMATEL technique by incorporating gray theory and conducting clarification operations during the analysis process, thereby ensuring the objectivity of our research results.

Through our thorough examination of the existing literature, we have arrived at two concise yet impactful conclusions. First, the adoption of GSCM practices plays a pivotal role in bolstering the sustainability and green efficiency of the electronics industry. Second, the utilization of MCDM methods presents a promising avenue for tackling the intricate, multifaceted decision-making challenges that arise within GSCM practices. These conclusions underscore the significance of incorporating environmental considerations into the supply chain management process and the potential advantages of leveraging advanced analytical tools to facilitate sustainable decision-making.

Here, we introduce the application of the GDEMATEL–AISM method to analyze the driving factors within China's electronics industry.

To obtain expert opinions, we shared the finalized list of driving factors and collected their input through the direct relation matrix, which captures the relationships between different factors. The questionnaire was completed by a panel of seven experts comprising individuals from the government, electronics industry organizations, and enterprises. These experts held positions such as head and manager, and possessed extensive experience and knowledge in the field. It is worth noting that in MCDM techniques, including DEMATEL, there are no specific rules limiting the number of respondents, and the DEMATEL method can be effectively employed even with a limited sample size (Lee et al., 2013; Hwang et al., 2016). Recent studies have also demonstrated the successful use of small sample sizes tin applying the DEMATEL method (Peng et al., 2022; Zhong et al., 2022). Therefore, our sample size of seven experts is deemed sufficient for this study.

We meticulously reviewed relevant studies to identify the driving factors associated with GSCM practices in the electronics industry. Subsequently, we engaged in discussions with an academic expert and two industry experts to validate the factors and seek their insights on potential additions or exclusions. The final list of driving factors, along with the corresponding references are shown in Table 1.

1.3. Motivation, research gap, and contribution

A comprehensive review of the literature reveals a notable gap in research concerning the application of GSCM within the electronics industry. While numerous studies delve into various aspects of GSCM, there is a dearth of research examining the drivers of GSCM in the industry as a whole. Furthermore, the relationship, role, and impact of these drivers have remained largely unexplored. Our study not only identifies these drivers, but also conducts a thorough causal and correlation analysis, enhancing our understanding of their interconnectedness. Additionally, we employ a network structure to visually depict the transmission between these factors. In order to emphasize the unique contributions of our research, Table 2 provides a summary of the key distinctions between our study and other relevant research endeavors.

In conclusion, this study makes several noteworthy contributions to the existing literature. First, it introduces a novel and comprehensive model called the GDEMATEL–AISM model, which facilitates an objective and clear evaluation of GSCM practices. Second, it identifies the key driving factors behind GSCM practices. Third, it establishes a topological hierarchy that effectively determines the relative importance of the identified factors and visually represents the relationships between these driving factors. Lastly, by analyzing and summarizing previous GSCM research, this study provides valuable insights that can guide future investigations in the field. The application of this innovative approach has the potential to contribute significantly to the sustainable development of developing countries and emerging economies, such as China (Jiang, 2000).

Table 1
List of drivers.

Number	Factors	Description	References
F1	green marketing	Efforts to design, promote, price, and distribute products that do not harm the environment.	Gelderman et al. (2021); Roh et al. (2022); Shi et al. (2022); Kar and Harichandan (2022)
F2	internal green management	The company formulates its own environmental protection policy and environmental goals to ensure environmental protection activities.	Hu et al. (2019); Agyabeng-Mensah et al. (2020); Bu et al. (2020); Visamitanan and Assarut (2021)
F3	green logistics	Integrate the activities required to move products throughout the supply chain in a sustainable manner.	Aldakhil et al. (2018); Islam et al. (2021); Khan et al. (2022); Sharma et al. (2023)
F4	green innovation	New products, methods, etc. that consider the impact on the environment throughout their life cycle.	Abbas et al. (2022); Le et al. (2022); Wang and Liu (2022); Hao et al. (2023)
F5	green procurement	Integrate environmental issues and concerns into the procurement process.	Trivedi et al. (2018); Hazaea et al. (2022); Khan et al. (2022); Khan et al. (2022)
F6	green cooperation	External cooperation along the supply chain to promote sustainable development activities.	Chen et al. (2019); Guo et al. (2021); Li et al. (2022); Yang et al. (2023)
F7	green R&D and design	Activities that integrate environmental considerations into product design while maintaining all functional and safety requirements of consumers.	Liu et al. (2018); Du et al. (2020); Chen et al. (2021); Li and Gao (2022)
F8	green manufacturing and production	Adopt and plan activities that require less energy and resource use in production systems and cause as little environmental pollution as possible.	Ghadimi et al. (2020); Rong et al. (2021); Shukla and Adil (2021); D'Angelo et al. (2022)
F9	green recycling	Attempt to incorporate end-of-life products and surplus items into the reverse logistics process.	Chen et al. (2019); Zarbakhshnia et al. (2019); Dev et al. (2020); Plaza-Úbeda et al. (2020); Paul and Ghosh (2022)
F10	green education	Teach environmental policy and change public behavior for more lasting and responsible relationships with the environment.	Galli et al. (2020); Rustam et al. (2020); Severo et al. (2021); Darvishmotevali and Altinay (2022)

1.4. Paper orientation

The remainder of this paper is organized as follows. Section 2 presents the methods and computational processes employed in this study. Section 3 applies and analyzes the model using a case from the Chinese electronics industry. Section 4 discusses the obtained results and findings. Finally, Section 5 provides a summary of the results and presents potential avenues for future research.

2. Methodology

2.1. Symbols and assumptions

The following table, labeled 3, presents the symbolic description used in this paper where $i = 1$ denotes the upper matrix, $i = 2$ denotes the lower matrix, and $i = 3$ denotes the sharpened matrix.

The following assumptions are made regarding the proposed method, and this paper will base its analysis on these assumptions.

(a) All of the experts' scoresheets are authentic, credible, and based on their own insights into the electronics industry.
(b) All of the experts' opinions have been taken into account.
(c) There is a transmissive interrelationship between all the drivers. The principle of transmissibility states that if factor A is connected to factor B and factor B is connected to factor C, then factor A will also be connected to factor C.
(d) The parties involved in the electronics industry are rational. They are driven by benefits and are willing to adopt various green behaviors in GSCM, thereby adding value.

2.2. GDEMATEL method

Step 1: Determine the gray linguistic scale.

We utilize a six-level gray linguistic scale for expert assessment (refer to Table 4), which allows us to break down each expert's score into upper and lower bounds. The scale consists of six levels: "no influence," "very low influence," "low influence," "medium influence," "high influence," and "very high influence.".

We process the sample data of the expert scores, obtain the average direct relation matrix, and transform the sample data into upper, lower, and sharpened matrices using the Likert scales ranging from 0 to 5 (refer to Table 4).

Step 2: Normalize the gray number matrix and calculate the crisp value.

Table 2
Major differences between this study and other studies.

Literature	Method	Key factors identification	Cause and effect and correlation analysis	Network structure visualization
Ososanmi, Ojo, Ogundimu and Oke Ososanmi et al. (2022)	Close-up approach	√		
Long, Tao, Shi and Zhang Long et al. (2021)	Evolutionary game model	√		√
Moreira, Ribau and da Silva Ferreira Rodrigues Moreira et al. (2022)	Regression analysis	√	√	
Bartos, Schwarzkopf, Mueller and Hofmann-Stoelting Bartos et al. (2022)	Regression analysis	√	√	
Liu, Eweje, He and Lin Liu et al. (2020)	PLS-SEM	√	√	
Huang et al. Huang et al. (2021)	Structural equation modeling	√		
Borazon et al. Borazon et al. (2021)	Structural equation modeling	√		
Khan et al. Khan et al. (2021)	Structural equation modeling	√		
Ilyas et al. Ilyas et al. (2020)	Structural equation modeling	√		
Zhao et al. Zhao et al. (2018)	System dynamics model	√		√
de Souza, Kerber, Bouzon and Rodriguez de Souza et al. (2022)	AHP	√		
Kaur et al. Kaur et al. (2018)	DEMATEL	√	√	
Li and Mathiyazhagan Li and Mathiyazhagan (2018)	DEMATEL	√	√	
Osintsev et al. Osintsev et al. (2021)	DEMATEL-ANP	√	√	
Lin et al. Lin et al. (2018)	Fuzzy DEMATEL	√	√	
Kumar and Anbanandam Kumar and Anbanandam (2020)	GDEMATEL-ANP	√	√	
Kumar and Anbanandam Kumar and Anbanandam (2020)	GDEMATEL-ANP	√	√	
Chakraborty, Al Amin and Baldacci Chakraborty et al. (2023)	ISM	√		√
Ghosh, Chandra Mandal and Ray Ghosh et al. (2022)	Item-PCA-Taguchi analysis	√	√	
Chatterjee et al. Chatterjee et al. (2018)	R'AMATEL–MAIRCA	√		
This study	GDEMATEL-AISM	√	√	√

Table 3
Symbols and descriptions in this paper.

Symbol	Description
A_i	Gray number matrix
k	The number of experts
Y_i	Total normalized crisp value matrix
Z	Final crisp value matrix
G	Normalized factor
x_i	Normalized direct relation matrix
I	Identity matrix
D_i	Impact degree
C_i	Influenced degree
M_i	Prominence
R_i	Relation
DM	Evaluation matrix
p_m	Positive index
q_m	Negative index
AM	Adjacent relation matrix
BM	The multiplication of adjacent matrix
RM	Reachability matrix
SM	General skeleton matrix
RS	Reachable set
QS	Prior set
TS	Common set

We normalize the gray number matrices A_1 and A_2 for the upper and lower bounds, respectively, using Eqs. (1) and (2), where k is the number of experts:

$$\overline{\otimes}\overline{x}_{ij}^{k} = \left(\overline{\otimes}x_{ij}^{k} - \min\overline{\otimes}x_{ij}^{k}\right)\Big/\Delta_{\min}^{\max}, \tag{1}$$

$$\underline{\otimes}\overline{x}_{ij}^{k} = \left(\underline{\otimes}x_{ij}^{k} - \min\underline{\otimes}x_{ij}^{k}\right)\Big/\Delta_{\min}^{\max}, \tag{2}$$

where $\Delta_{\min}^{\max} = \max\overline{\otimes}x_{ij}^{k} - \min\underline{\otimes}x_{ij}^{k}$.

After the gray number normalization, we calculate the total normalized crisp value using Eq. (3):

$$Y_{ij}^{k} = \frac{\underline{\otimes}\overline{x}_{ij}^{k}\left(1-\underline{\otimes}\overline{x}_{ij}^{k}\right) + \overline{\otimes}\overline{x}_{ij}^{k} \times \overline{\otimes}\overline{x}_{ij}^{k}}{1-\underline{\otimes}\overline{x}_{ij}^{k} + \overline{\otimes}\overline{x}_{ij}^{k}}. \tag{3}$$

Finally, we calculate the final crisp value using Eq. (4):

$$Z_{ij}^{k} = \min_{j}\underline{\otimes}x_{ij}^{k} + Y_{ij}^{k}\Delta_{\min}^{\max}. \tag{4}$$

A matrix consisting of crisp value elements is referred to as a sharpened (or crisp value) matrix.

Step 3: Construct the normalized direct relation matrix.

We calculate the normalized direct relation matrix X_1 for the upper direct relation matrix A_1 using Eqs. (5) and (6). All elements in this matrix are between 0 and 1.

$$G = \frac{1}{\max\limits_{1\leqslant i\leqslant n}\sum_{j=1}^{n} a_{1ij}}, \tag{5}$$

$$X_1 = G * A_1, \tag{6}$$

Table 4
Expert assessment gray language scale.

Linguistic term	Grey numbers	Influence score	Upper matrix value	Lower matrix value
No influence	[0,0]	0	0	0
Very low influence	[0,0.25]	1	0.25	0
Low influence	[0.25,0.5]	2	0.5	0.25
Medium influence	[0.5,0.75]	3	0.75	0.5
High influence	[0.75,1]	4	1	0.75
Very high influence	[1,1]	5	1	1

where X_1 is the normalized direct relation matrix and G is the normalized factor.

Using the same method, we construct the normalized lower direct relation matrix X_2 and normalized sharpened matrix X_3.

Step 4: Construct the total relation matrix.

We obtain the upper total relation matrix Y_1 from the normalized matrix X_1 through Eq. (7), where I represents the identity matrix:

$$Y_1 = X_1(I - X_1)^{-1}. \tag{7}$$

Similarly, a lower total relation matrix Y_2 and sharpened total relation matrix Y_3 is obtained.

Step 5: Calculate the sum of the rows and columns of the total relation matrix.

$$D_1 = \left[\sum_{j=1}^{j=n} y_{1ij}\right]_{n\times 1}, \tag{8}$$

$$C_1 = \left[\sum_{i=1}^{i=n} y_{1ij}\right]'_{1\times n}. \tag{9}$$

In Eq. (8), D_1 represents the sum of the rows of upper total relation matrix Y_1 and is referred to as the upper impact degree. In Eq. (9), C_1 represents the sum of the columns of upper total relation matrix Y_1 and is referred to as the upper influenced degree. Similarly, the D_2, D_3, C_2, C_3 for the lower and sharpened matrices are calculated.

Step 6: Constructing causal relationships.

Based on the dataset composed of $(D_i + C_i, D_i - C_i)(i = 1, 2, 3)$, we establish the Cartesian coordinate systems for the upper bound, lower bound, and sharpened matrices, respectively. Subsequently, the influencing factors (i.e., the causal relationship graph) can be plotted in the coordinate system. Moreover, based on the average and standard deviation of the total relation matrix Y, the relationships between them can be marked on the graph, with the prominence (M_i) and relation (R_i) obtained from the three recorded matrices.

Step 7: Discuss topological invariance.

We sort the obtained $M_i, R_i(i = 1, 2, 3)$ in ascending order and obtain the sorting results M_{sort}, R_{sort} based on centrality and causality; Then, we examine the sorted results. If in M_{sort}, R_{sort}, the corresponding elements of each place are always the same (e.g., in the upper bound, lower bound, and sharpened matrices, the element with the largest centrality R is always 5), the prominence and relation matrices $M_i, R_i(i = 1, 2, 3)$ are said to have topological invariance.

Step 8: Constructing the overall causal relationship.

If the prominence and relation matrices $M_i, R_i(i = 1, 2, 3)$ possess topological invariance, the three causal relationship graphs established in step 6 can be drawn on a single graph, and their movement trajectories can be displayed.

2.3. AISM method

Step 1: Constructing the adjacency relation matrix.

Based on the partial order calculation, we transform the evaluation matrix into a relation matrix through the partial order relationship operation. The specific partial order rules are as follows.

For an evaluation matrix DM containing m columns, the larger the matrix value, the better, and the smaller the matrix value, the worse. This is referred to as a positive index, denoted as $p_1, p_2 \cdots p_m$. Conversely, if the matrix value is smaller, it is a negative index denoted as $q_1, q_2 \cdots q_m$. For any two rows x and y in DM, if it is a positive index,

$$dm_{(x,p_1)} \geqslant dm_{(y,p_1)}, dm_{(x,p_2)} \geqslant dm_{(y,p_2)}, \cdots, dm_{(x,p_m)} \geqslant dm_{(y,p_m)}; \tag{10}$$

and if it is a negative index,

$$dm_{(x,q_1)} \leqslant dm_{(y,q_1)}, dm_{(x,q_2)} \leqslant dm_{(y,q_2)}, \cdots, dm_{(x,q_m)} \leqslant dm_{(y,q_m)}. \tag{11}$$

If the above rules are satisfied, the partial order relationship between x and y is denoted as $x \prec y$, indicating that y is better than x. Consequently, by utilizing expert scoring, the internal relationship between each influencing factor can be determined based on different evaluation indicators. Element am_{ij} in the adjacent relation matrix AM can be represented as

$$am_{ij} = \left\{ \begin{array}{ll} 0, & x \prec y \\ 1, & \text{No perfect relationship between } x \text{ and } y. \end{array} \right\} \tag{12}$$

Step 2: Constructing the general skeleton matrix SM.

The reachability matrix describes the degree to which the nodes in a directed graph can be reached through a certain path length. For an arbitrary original matrix, our first step is to calculate the multiplication adjacent matrix BM:

$$BM = AM + I, \tag{13}$$

where BM is the multiplication adjacent matrix and I is the identity matrix. By multiplying BM repeatedly, a reachability matrix RM can be obtained:

$$BM^{k-1} \neq BM^k = BM^{k+1} = RM. \tag{14}$$

Our next step is to perform point reduction on the reachability matrix RM. Point reduction is the process of treating the cycles in the reachability matrix RM as one point, resulting in a new reachability matrix RM'. Edge reduction can then be performed on RM' to obtain the skeleton matrix SM', which essentially eliminates duplicate paths.

$$SM' = RM' - (RM' - I)^2 - I. \tag{15}$$

If the cycles in SM' are represented by the simplest chrysanthemum chains, a general skeleton matrix SM can be obtained.

Step 3: Hierarchy extraction.

For a reachable matrix, a reachable set RS, prior set QS, and common set TS exist, where $TS = RS \cap QS$. Taking the relation matrix AM as an example, element am_{ij}, can fall into the following cases: (1) all elements corresponding to a row value of 1 for an element are referred to as the reachable set $RS = am_{ij}$; (2) all elements corresponding to a column value of 1 for an element are referred to as the prior set $QS(am_{ij})$. The

Table 5
Normalized upper direct relation matrix.

Factors	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
F1	0.000	0.350	0.175	0.000	0.000	0.350	0.088	0.000	0.263	0.700
F2	0.788	0.000	0.613	0.700	1.051	0.613	0.350	0.350	0.876	0.350
F3	1.051	0.438	0.000	0.963	1.051	0.788	0.088	0.088	1.051	0.700
F4	0.000	0.088	0.525	0.000	0.000	0.000	0.963	0.000	0.000	0.438
F5	0.350	0.876	0.438	1.051	0.000	0.000	1.051	0.000	0.963	0.175
F6	0.525	0.000	0.088	0.876	0.263	0.000	0.175	0.000	0.438	0.000
F7	0.000	0.350	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.438
F8	1.051	1.051	1.051	1.051	1.051	0.876	0.088	0.000	1.051	0.000
F9	0.088	0.263	0.350	0.000	0.000	0.000	0.000	0.263	0.000	0.963
F10	0.088	0.088	0.438	0.788	0.525	0.000	0.000	0.350	0.088	0.000

Table 6
Normalized lower direct relation matrix.

Factors	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
F1	0.000	0.236	0.118	0.000	0.000	0.471	0.000	0.000	0.236	0.589
F2	0.707	0.000	0.471	0.589	1.060	0.471	0.236	0.236	0.825	0.118
F3	1.060	0.353	0.000	0.943	1.060	0.707	0.000	0.000	1.060	0.589
F4	0.000	0.000	0.353	0.000	0.000	0.000	0.943	0.000	0.000	0.471
F5	0.236	0.825	0.236	1.060	0.000	0.000	1.060	0.000	0.943	0.118
F6	0.471	0.000	0.000	0.825	0.000	0.000	0.118	0.000	0.353	0.000
F7	0.000	0.353	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.353
F8	1.060	1.060	1.060	1.060	1.060	0.825	0.000	0.000	1.060	0.000
F9	0.000	0.118	0.353	0.000	0.000	0.000	0.000	0.236	0.000	0.943
F10	0.000	0.000	0.471	0.707	0.471	0.000	0.000	0.471	0.000	0.000

Table 7
Normalized sharpened direct relation matrix.

Factors	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
F1	0.000	0.239	0.107	0.000	0.000	0.367	0.007	0.000	0.206	0.613
F2	0.724	0.000	0.502	0.613	1.057	0.502	0.239	0.239	0.835	0.169
F3	1.057	0.344	0.000	0.946	1.057	0.724	0.007	0.007	1.057	0.613
F4	0.000	0.007	0.391	0.000	0.000	0.000	0.946	0.000	0.000	0.404
F5	0.239	0.835	0.280	1.057	0.000	0.000	1.057	0.000	0.946	0.107
F6	0.450	0.000	0.007	0.835	0.058	0.000	0.107	0.000	0.344	0.000
F7	0.000	0.305	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.344
F8	1.057	1.057	1.057	1.057	1.057	0.835	0.007	0.000	1.057	0.000
F9	0.007	0.133	0.305	0.000	0.000	0.000	0.000	0.206	0.000	0.946
F10	0.007	0.007	0.404	0.724	0.450	0.000	0.000	0.367	0.007	0.000

Table 8
Upper total relation matrix.

Factors	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
F1	0.3992	0.4079	−0.5025	−0.2959	−0.3219	−0.0700	0.2541	0.5190	0.1172	−0.1167
F2	0.3740	0.1195	−0.9090	−0.0427	−0.7443	0.0830	0.6972	0.0828	0.3705	−0.6519
F3	0.4815	0.3295	−1.1176	−0.8510	−0.3409	−0.0003	0.2052	0.2097	0.1246	−0.0221
F4	−0.4926	−0.3359	0.1206	−0.2017	−0.0191	−0.0065	−0.2092	−0.2144	−0.1269	−0.3992
F5	−1.3018	−0.8428	0.3319	−0.5950	0.2020	−0.2738	−0.5249	−0.5591	−0.3154	0.3056
F6	−0.2258	−0.3015	0.0121	−0.3774	0.1887	−0.1593	−0.1877	−0.1225	−0.1239	0.2709
F7	−0.6136	−0.4184	0.1503	0.9943	−0.0238	−0.0081	−0.2606	−0.2670	−0.1581	−0.4973
F8	1.3475	0.3555	−0.4948	−0.3496	−0.2864	−0.0941	0.2214	0.4936	0.0962	−0.0485
F9	−0.1138	−0.0764	0.0282	0.1111	−0.3776	−0.0085	−0.0476	−0.0493	−0.0288	−0.5202
F10	−1.0097	−0.6545	0.2572	−0.4096	0.4604	−0.2075	−0.4076	−0.4338	−0.2450	−0.3005

common set of reachable set $RS = (am_{ij}) \cap QS(am_{ij})$, and the prior set is referred to as $TS(am_{ij})$.

The specific extraction method is as follows. (1) UP-type topological structure extraction. The UP-type structure, also known as result–-priority hierarchy extraction, follows the rule $TS(am_{ij}) = RS(am_{ij})$. This method involves extracting the elements representing the final result from the system, placing them on the top layer, and then extracting them by analogy. (2) DOWN-type topological structure extraction. The DOWN-type structure is a cause-based hierarchy extraction method with the rule $TS(am_{ij}) = QS(am_{ij})$. In this method, the elements serving as the root cause in the system are first extracted and placed at the bottom of the hierarchy structure, followed by extraction by analogy.

Step 4: Drawing the directed topological hierarchy graph.

Based on the relationships and results of the extracted hierarchical elements, a set of directed topological hierarchy graphs can be drawn.

3. Result

3.1. Analysis results of the proposed method

The normalized direct relation matrix can be calculated (refer to Tables 5–7). Subsequently, the overall relation matrix can be calculated with simple numerical calculations (refer to Tables 8–10).

Tables 8–10 display the upper, lower, and sharpened total relation matrices, respectively.

The net cause and net receiver factors are obtained from the total relation matrix, the results of which are presented in Tables 11–13. Finally, the values of each row (D) and column (C) are calculated using Eqs. 8 and 9 in Step 5 to obtain the prominence ($R + C$) and relation ($R - C$).

The following discusses topological invariance. Table 14 displays the sorted prominence, while Table 15 presents the relation.

Since the factors corresponding to the two matrices remained unchanged after sorting, it can be concluded that prominence and relation exhibit topological invariance. Therefore, it is possible to construct the overall causal relationship among the various factors. The visualization of this relationship is depicted in Fig. 1, where the movement trajectory is also annotated.

The analysis using the AISM method is presented below. Table 16 illustrates the initial evaluation matrix DM. Based on the method discussed in the previous section, the internal relation matrix AM (refer to Table 17) and the multiplication adjacent matrix BM (refer to Table 18) can be established.

After a series of multiplicative operations, a reachable matrix RM can be obtained from the product adjacent matrix, as presented in Table 19. Subsequently, by conducting a series of topological operations and eliminating duplicate paths, the general skeleton matrix S is obtained and presented in Table 20.

Using the general skeleton matrix SM, hierarchical extraction can be carried out, resulting in the creation of two directed, opposing hierarchical topological graphs (see Fig. 2).

Table 9
Lower total relation matrix.

Factors	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
F1	0.8717	0.7374	−0.8628	−0.4122	−0.3505	−0.1737	0.4135	1.0496	0.2067	−0.3063
F2	0.3439	0.0121	−0.8896	−0.1361	−0.4833	−0.0732	0.5676	0.1928	0.2838	−0.6055
F3	0.3371	0.2265	−1.1064	−1.0175	−0.1261	0.0356	0.1270	0.1890	0.0635	0.0562
F4	−0.5490	−0.3690	0.1733	−0.1282	−0.0914	−0.0580	−0.2069	−0.3079	−0.1035	−0.4243
F5	−1.6716	−1.1235	0.5277	−0.6203	0.1792	−0.1766	−0.6300	−0.9374	−0.3150	0.3428
F6	−0.4793	−0.3222	0.1513	−0.3063	0.1524	−0.0506	−0.1806	−0.2688	−0.0903	0.3106
F7	−0.6927	−0.4656	0.2187	1.0999	−0.1154	−0.0732	−0.2611	−0.3884	−0.1305	−0.5354
F8	1.8368	0.7236	−0.8466	−0.4045	−0.3439	−0.1704	0.4057	1.0300	0.2029	−0.3006
F9	−0.3620	−0.2433	0.1143	0.1014	−0.2391	−0.0382	−0.1364	−0.2030	−0.0682	−0.4803
F10	−1.2521	−0.8415	0.3952	−0.3891	0.4045	−0.1323	−0.4719	−0.7021	−0.2359	−0.2802

Table 10
Sharpened total relation matrix.

Factors	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
F1	0.4663	0.4198	−0.5216	−0.3148	−0.1992	−0.0734	0.2237	0.6028	0.1144	−0.1333
F2	0.2570	−0.0290	−0.8352	−0.1549	−0.4631	−0.0076	0.5173	0.0871	0.2683	−0.5459
F3	0.2997	0.1933	−1.0571	−0.9746	−0.1227	0.0350	0.1030	0.1261	0.0545	0.0702
F4	−0.4426	−0.2853	0.0844	−0.1623	−0.1337	−0.0577	−0.1520	−0.1863	−0.0805	−0.4606
F5	−1.3688	−0.8811	0.2617	−0.7129	0.0657	−0.2108	−0.4694	−0.5760	−0.2484	0.2311
F6	−0.3056	−0.2373	0.0398	−0.3163	0.1120	−0.0710	−0.1264	−0.1297	−0.0672	0.2449
F7	−0.5567	−0.3589	0.1062	1.0536	−0.1682	−0.0725	−0.1912	−0.2343	−0.1012	−0.5793
F8	1.4493	0.4112	−0.5173	−0.3181	−0.1949	−0.0747	0.2191	0.5957	0.1120	−0.1263
F9	−0.2584	−0.1664	0.0494	0.0835	−0.2904	−0.0376	−0.0887	−0.1087	−0.0469	−0.5095
F10	−1.0432	−0.6715	0.1994	−0.4735	0.3351	−0.1600	−0.3578	−0.4390	−0.1893	−0.3611

Table 11
Upper matrix factor prominence and relation.

Factors	D	C	M	R
F1	0.3904	−1.1553	−0.7648	1.5457
F2	−0.6209	−1.4169	−2.0378	0.7961
F3	−0.9813	−2.1235	−3.1048	1.1422
F4	−1.8850	−2.0174	−3.9023	0.1324
F5	−3.5732	−1.2628	−4.8361	−2.3104
F6	−1.0263	−0.7452	−1.7715	−0.2811
F7	−1.1023	−0.2596	−1.3619	−0.8426
F8	1.2408	−0.3410	0.8998	1.5817
F9	−1.0829	−0.2897	−1.3726	−0.7932
F10	−2.9506	−1.9799	−4.9305	−0.9707

Table 12
Lower matrix factor prominence and relation.

Factors	D	C	M	R
F1	1.1734	−1.6173	−0.4438	2.7907
F2	−0.7875	−1.6655	−2.4530	0.8780
F3	−1.2151	−2.1249	−3.3400	0.9098
F4	−2.0650	−2.2130	−4.2780	0.1480
F5	−4.4248	−1.0135	−5.4383	−3.4112
F6	−1.0838	−0.9107	−1.9945	−0.1731
F7	−1.3437	−0.3732	−1.7169	−0.9705
F8	2.1328	−0.3461	1.7867	2.4789
F9	−1.5548	−0.1866	−1.7413	−1.3682
F10	−3.5053	−2.2230	−5.7284	−1.2823

Table 13
Sharpened matrix factor prominence and relation.

Factors	D	C	M	R
F1	0.5846	−1.5031	−0.9184	2.0877
F2	−0.9060	−1.6052	−2.5112	0.6991
F3	−1.2725	−2.1903	−3.4628	0.9178
F4	−1.8765	−2.2904	−4.1669	0.4139
F5	−3.9090	−1.0594	−4.9684	−2.8496
F6	−0.8568	−0.7302	−1.5870	−0.1266
F7	−1.1025	−0.3224	−1.4249	−0.7801
F8	1.5558	−0.2623	1.2935	1.8180
F9	−1.3738	−0.1844	−1.5582	−1.1894
F10	−3.1608	−2.1699	−5.3307	−0.9909

Table 14
Sorted prominence.

Sort	Upper	Factors	Lower	Factors	Sharpened	Factors
1	−4.9305	F10	−5.7284	F10	−5.3307	F10
2	−4.8361	F5	−5.4383	F5	−4.9684	F5
3	−3.9023	F4	−4.2780	F4	−4.1669	F4
4	−3.1048	F3	−3.3400	F3	−3.4628	F3
5	−2.0378	F2	−2.4530	F2	−2.5112	F2
6	−1.7715	F6	−1.9945	F6	−1.5870	F6
7	−1.3726	F9	−1.7413	F9	−1.5582	F9
8	−1.3619	F7	−1.7169	F7	−1.4249	F7
9	−0.7648	F1	−0.4438	F1	−0.9184	F1
10	0.8998	F8	1.7867	F8	1.2935	F8

3.2. Sensitivity analysis

To assess the robustness of the proposed integrated method, we conduct a sensitivity analysis to examine the potential impact of bias from the seven specific experts on the results. We focus on analyzing the variance of decision outcomes under different expert weight settings. In our study, we adjust the weight of one expert to 0.4 and the weights of the remaining experts to 0.1. This adjustment is applied in seven scenarios, with each scenario altering the weight distribution. By comparing the results of these seven scenarios, we aim to maximize the robustness of the method.

The sensitivity analysis results, presented in Fig. 3, illustrate the prominence-relation diagrams for the different scenarios along with their corresponding topological maps of the adversarial hierarchy. Across all experiments, F1 and F8 maintain their positions at the result level, while F4 remains at the root level. This consistency indicates that the drivers of the most significant GSCM practices remain largely unchanged. Moreover, the prominence-relation diagrams exhibit similarity in causal clusters among the seven scenarios. Based on these findings, we can confidently conclude that the results obtained from the GDEMATEL-AISM method are reliable and suitable for decision-making purposes.

Table 15
Sorted relation.

Sort	Upper	Factors	Lower	Factors	Sharpened	Factors
1	−2.3104	F5	−3.4112	F5	−2.8496	F5
2	−0.9707	F9	−1.3682	F9	−1.1894	F9
3	−0.8426	F10	−1.2823	F10	−0.9909	F10
4	−0.7932	F7	−0.9705	F7	−0.7801	F7
5	−0.2811	F6	−0.1731	F6	−0.1266	F6
6	0.1324	F4	0.1480	F4	0.4139	F4
7	0.7961	F2	0.8780	F2	0.6991	F2
8	1.1422	F3	0.9098	F3	0.9178	F3
9	1.5457	F8	2.4789	F8	1.8180	F8
10	1.5817	F1	2.7907	F1	2.0877	F1

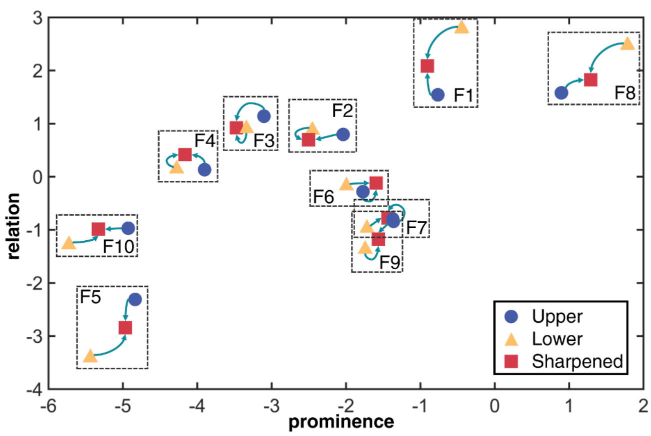

Fig. 1. Overall prominence-relation of the 10 factors.

4. Discussion

4.1. Discussion of the results

4.1.1. Centrality and Causality Analysis

Factors with high prominence values play a significant role in influencing other factors and should be given priority. Among them, green manufacturing and production (F8) exhibits the highest prominence value, indicating its strong correlation with other factors. Following closely is green marketing (F1), which also demonstrates a relatively high prominence value. In terms of the relation value, a positive value signifies that a factor influences other factors, whereas a negative value indicates that a factor is influenced by other. The magnitude of the relation value reflects the extent of the impact. As depicted in Fig. 1, green manufacturing and production (F8) and green marketing (F1) exert a substantial influence on other factors, while green procurement (F5) is significantly influenced by other factors.

4.1.2. System Activation Analysis

In a directed acyclic topological hierarchy, a system containing

Table 17
Internal relation matrix.

Factors	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
F1	0	0	0	0	0	0	0	0	0	0
F2	1	0	0	0	0	0	1	1	0	0
F3	1	0	0	0	0	0	0	1	0	0
F4	1	1	1	0	0	0	1	1	1	0
F5	0	0	0	0	0	0	0	0	0	0
F6	1	0	0	0	0	0	1	1	1	0
F7	1	0	0	0	0	0	0	1	0	0
F8	0	0	0	0	0	0	0	0	0	0
F9	1	0	0	0	0	0	0	1	0	0
F10	1	0	0	0	1	0	0	1	0	0

Table 18
Multiplicative adjacency matrix.

Factors	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
F1	1	0	0	0	0	0	0	0	0	0
F2	1	1	0	0	0	0	1	1	0	0
F3	1	0	1	0	0	0	0	1	0	0
F4	1	1	1	1	0	0	1	1	1	0
F5	0	0	0	0	1	0	0	0	0	0
F6	1	0	0	0	0	1	1	1	1	0
F7	1	0	0	0	0	0	1	1	0	0
F8	0	0	0	0	0	0	0	1	0	0
F9	1	0	0	0	0	0	0	1	1	0
F10	1	0	0	0	1	0	0	1	0	1

Table 19
Reachable matrix.

Factors	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
F1	1	0	0	0	0	0	0	0	0	0
F2	1	1	0	0	0	0	1	1	0	0
F3	1	0	1	0	0	0	0	1	0	0
F4	1	1	1	1	0	0	1	1	1	0
F5	0	0	0	0	1	0	0	0	0	0
F6	1	0	0	0	0	1	1	1	1	0
F7	1	0	0	0	0	0	1	1	0	0
F8	0	0	0	0	0	0	0	1	0	0
F9	1	0	0	0	0	0	0	1	1	0
F10	1	0	0	0	1	0	0	1	0	1

Table 16
Initial evaluation matrix.

Factors	M1	M2	M3	|R1|	|R2|	|R3|
F1	−0.7648	−0.4438	−0.9184	1.5457	2.7907	2.0877
F2	−2.0378	−2.4530	−2.5112	0.7961	0.8780	0.6991
F3	−3.1048	−3.3400	−3.4628	1.1422	0.9098	0.9178
F4	−3.9023	−4.2780	−4.1669	0.1324	0.1480	0.4139
F5	−4.8361	−5.4383	−4.9684	2.3104	3.4112	2.8496
F6	−1.7715	−1.9945	−1.5870	0.2811	0.1731	0.1266
F7	−1.3619	−1.7169	−1.4249	0.8426	0.9705	0.7801
F8	0.8998	1.7867	1.2935	1.5817	2.4789	1.8180
F9	−1.3726	−1.7413	−1.5582	0.7932	1.3682	1.1894
F10	−4.9305	−5.7284	−5.3307	0.9707	1.2823	0.9909

Table 20
General skeleton matrix.

Factors	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
F1	0	0	0	0	0	0	0	0	0	0
F2	0	0	0	0	0	0	1	0	0	0
F3	1	0	0	0	0	0	0	1	0	0
F4	0	1	1	0	0	0	0	0	1	0
F5	0	0	0	0	0	0	0	0	0	0
F6	0	0	0	0	0	0	1	0	1	0
F7	1	0	0	0	0	0	0	1	0	0
F8	0	0	0	0	0	0	0	0	0	0
F9	1	0	0	0	0	0	0	1	0	0
F10	1	0	0	0	1	0	0	1	0	0

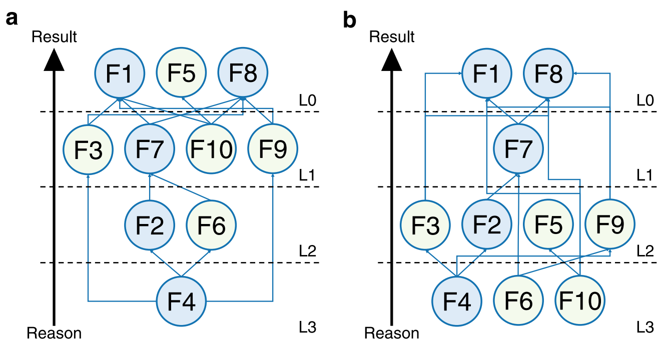

Fig. 2. (**a**) UP-type, (**b**) DOWN-type four-layer directed adversarial hierarchy topology diagram.

active factors is referred to as an active system, while a system without active factors is considered rigid. The activity of factors within the hierarchy determines their status as active factors, reflecting their influence. In the directed topological hierarchy illustrated in Fig. 2, the factors highlighted with light yellow markings represent active factors, indicating their system's active nature. For instance, green procurement (F5) is an active factor that transitions from L2 to L0. Hence, the active factors–green logistics (F3), green procurement (F5), green cooperation (F6), green recycling (F9), and green education (F10)– have multidimensional and multifaceted impacts on the GSCM of the electronics industry in China.

4.1.3. Hierarchy and Causality Analysis

As depicted in Fig. 2, the system exhibits a four-layer topological structure. The directed lines connecting the factors represent the causal relationships between them. The hierarchical levels assigned to the factors indicate their respective influences on the overall system. In this hierarchy, factors with larger levels exert greater impacts on the entire system.

Table 21 reflects the causal relationships in the topology diagram of Fig. 2. The third row of Table 21 shows the fixed drivers for each layer, which, to some extent, represent the optimal driving path.

The root layer factors dominate the system and occupy the bottom-most level. As evident in the topological graph (Fig. 2), factors at this level solely emit upward-directed segments. Within this system, the root layer factors consist of green innovation (F4), green cooperation (F6), and green education (F10). These factors possess the capability to directly or indirectly influence other factors within the system and exert a dominant effect on the entire system. They have the greatest impact on the long-term maintenance of GSCM practices.

The intermediate layer factors serve as the bridge between the root layer and the result layer. The factors at this level are influenced by the

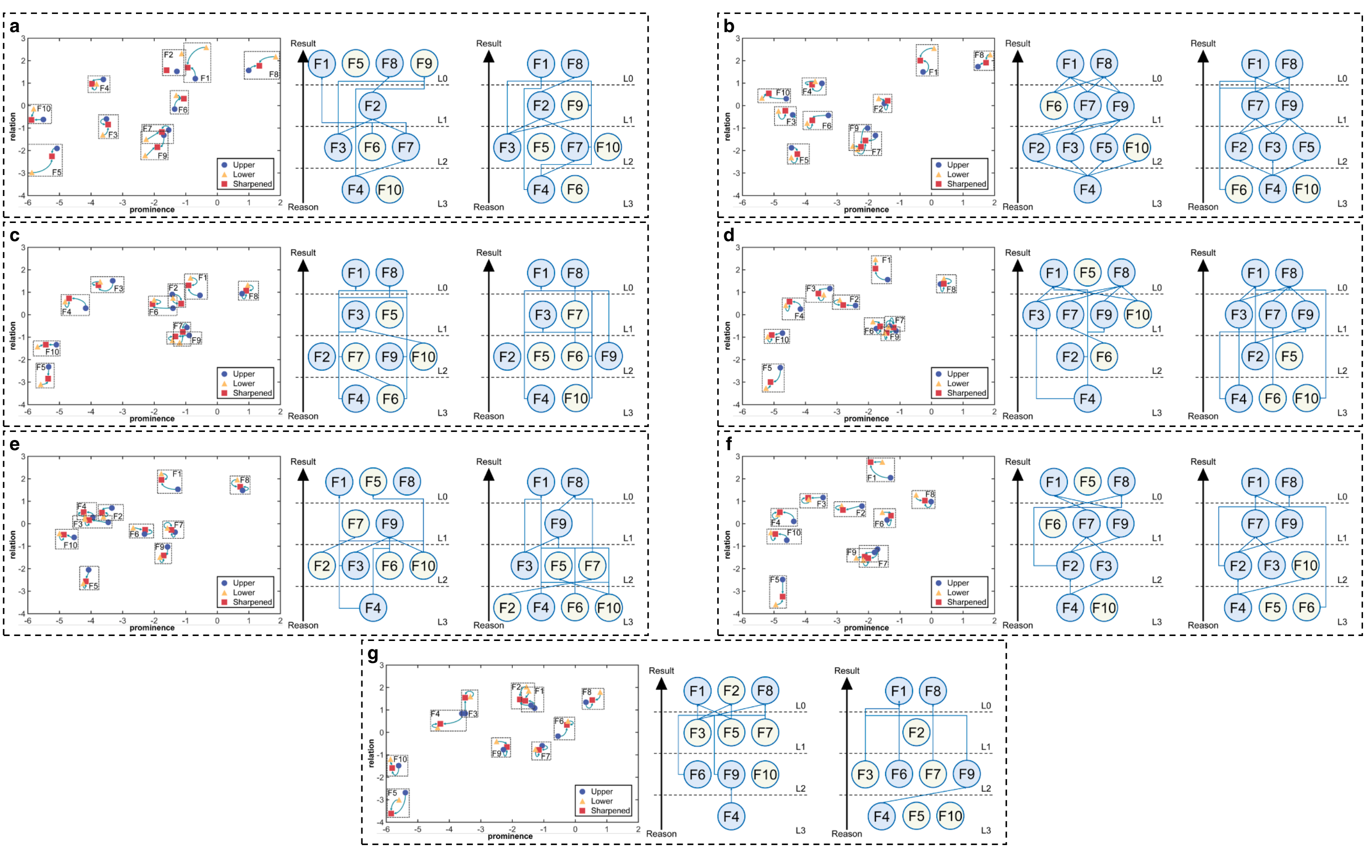

Fig. 3. Prominence-relation diagrams for different scenarios with their corresponding adversarial hierarchy topologies. **(a)** Scenario 1; **(b)** Scenario 2; **(c)** Scenario 3; **(d)** Scenario 4; **(e)** Scenario 5; **(f)** Scenario 6; **(g)** Scenario 7.

root layer factors while also emitting upward-directed segments. Within this system, the intermediate layer spans two levels, namely L1 and L2. It comprises four factors: internal green management (F2), green logistics (F3), green research and design (R&D) and design (F7), and green recovery (F9). These factors should be given priority in the optimization process to enhance the system's connectivity performance.

The result layer factors represent the direct agents of system change and occupy the topmost level. The factors at this level are solely influenced by directed segments from other levels, and all other factors must directly influence the system through this layer. In this system, the result layer factors include green marketing (F1), green manufacturing and production (F5), and green procurement (F8). These factors require attention in practice and should be optimized in the short-term to ensure their alignment with GSCM practices.

4.2. Implications and Recommendations

4.2.1. Theoretical implications

While the field of GSCM has been extensively researched across various industries and from different perspectives, there is still a dearth of research focused on understanding the drivers specific to the electronics industry. Our study aims to address this gap by providing a comprehensive set of drivers that play a crucial role in implementing sustainable supply chain practices within the electronics industry. This contribution complements existing theoretical frameworks and offers potential applicability to other industry contexts as well. Moreover, the study delves into the intricate interplay between different drivers and identifies the key drivers that influence GSCM practices in the electronics industry. Unlike subjective investigation methods, the mixed methodology employed in this study generates findings that can support future research on the rationality and stability of system structures. The proposed DEMATEL–AISM methodology has been validated as an effective systems technique, and the results of this study will enhance the GSCM literature and provide valuable insight for planning of GSCM practices not only in the electronics industry but also in other industries.

4.2.2. Managerial implications and policy recommendations

In the realm of GSCM, it is crucial to recognize the interconnections and transmission of factors within the system. These factors are intricately linked, and the effective performance of one factor can influence the performance of others. For instance, advancements in green innovation (F4) can drive technological progress and the development of diverse distribution modes in green logistics (F3), thereby facilitating the growth of green marketing (F1) and achieving a balance between consumer demand, corporate supply levels, and environmental benefits.

Green innovation (F4) holds a pivotal position as a root level driver and is considered the most critical catalyst for sustainable business performance. When suppliers strive for greater economic benefits through green innovation, it becomes imperative to foster green collaboration to attain their objectives (Zhu et al., 2017). Furthermore, green innovation can act as partial mediator between green management and green performance within the organization (Abbas et al., 2022). These findings support our study's assertion that engaging in continuous green innovation enhances the influence of the upward-directed line segment in Fig. 2. To address the challenge of green innovation, governments should develop economic and environmental policies that attract investment in renewable or energy-efficient projects, encourage increased R&D, and promote spending on green technologies. Corporate policy makers should strengthen collaborations with supply chain partners, universities, and public institutions to enhance green R&D capabilities and product quality management. Additionally, internal green training programs should be implemented to alleviate practitioners' resistance to adopting new systems and to raise awareness of the benefits of GSCM practices.

The factors that require optimization are green marketing (F1) and green manufacturing and production (F8), as they directly ensure the smooth functioning of the supply chain system. Optimization and innovation in green marketing can effectively position companies in the market through products incorporating green and sustainable technologies (Roh et al., 2022). For instance, Apple, an iconic electronics company, utilizes recycled and renewable materials in its technological products and publishes environmental reports for each product (Inc, 2022), thereby enhancing its green performance. Green manufacturing and production can reduce costs associated with pollution management, waste disposal, and materials/inventory handling (Baah et al., 2021). Moreover, it contributes to a healthier work environment, safer consumer products, increased social satisfaction, and improved corporate performance (Shokri and Li, 2020). To address the challenges related to green marketing and green manufacturing and production, managers should proactively enhance inter-functional coordination, participate in environment-related programs or meetings, provide training and technical expertise to employees, and align R&D efforts with green development goals to produce environmentally aligned products. Once products with green attributes are established, proactive strategies should be devised, emphasizing sustainability to avoid overconsumption and consumer skepticism, which may lead to exaggerated claims of benefits.

Table 21
List of causes and effects.

Up	{F1, F5, F8} ≻ {F3, F7, F9, F10} ≻ {F2, F6} ≻ {F4}
Down	{F1, F8} ≻ {F7} ≻ {F2, F3, F5, F9} ≻ {F4, F6, F10}
Fixed	{F1, F8} ≻ {F7} ≻ {F2} ≻ {F4}

5. Conclusion

GSCM practices are widely implemented in the electronics industry, making it essential to identify the driving factors involved. In this study, we utilized the GDEMATEL–AISM method to analyze the interrelationships and interaction mechanisms among these drivers. We classified them into different levels to identify key drivers, providing a valuable reference for future GSCM practices in the electronics industry. The main findings of this paper are summarized as follows:

(a) Ten potential drivers of GSCM practices in the electronics industry were identified, including green marketing, internal green management, and green logistics, which comprehensively represent the practical landscape.
(b) Green innovation emerged as the most crucial factor of GSCM practices in the electronics industry. Moreover, we discovered a direct correlation between the level of green manufacturing and production, green marketing, and the industry's overall green performance.
(c) Based on the relationship between different drivers, we provide recommendations to stakeholders in GSCM practices within the electronics industry. These recommendations include emphasizing factor linkages, strengthening cooperation, increasing investment in green R&D, promoting green marketing efforts, and enhancing strategic planning.
(d) The purposed method effectively captures the fuzziness in experts' evaluations and demonstrates the interaction and dependence among driving factors without compromising the system's functionality.

While this study has its limitations, it also presents directions for future research. The evaluations provided by experts are influenced by their decision-making and management perspectives, which may introduce personal biases. Additionally, the identification of GSCM drivers can be complex and challenging, considering the diverse nature of the field. Furthermore, the scope of this study is limited to China, and it is important to test the method and driving factors identified in this study using cases from other countries. Exploring alternative multi-criteria decision models or statistical techniques such as MAUT, TOPSIS, VIKOR, AHP, and BWM from different perspectives and comparing the results with the inferences of this study would be beneficial. Although the proposed GDEMATEL–AISM approach is specifically applicable to the electronics industry, it can be extended to other industries such as energy, mechanical engineering, construction, or manufacturing.

Data collection protocol

The data supporting the findings of this study are available from the corresponding author upon request.

CRediT authorship contribution statement

Yi Li: Conceptualization, Methodology, Investigation, Formal analysis, Writing - original draft, Writing - review & editing, Validation. **Yongqi Tan:** Software, Data curation, Formal analysis, Writing - review & editing, Validation. **Yang Pu:** Software, Data curation, Formal analysis, Writing - review & editing, Validation. **Yunying Zhu:** Formal analysis, Writing - review & editing. **Haotian Xie:** Conceptualization, Methodology, Investigation, Software, Data curation, Formal analysis, Writing - review & editing, Validation, Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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